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# Comparing Li-ion to Lead-Acid Batteries & Other Storage Options: Future Predictions

AVICENNE ENERGY US  
Michael SANDERS

## Presentation Outline

- The rechargeable battery market in 2017
- The Li-ion battery value chain
- Li-ion battery material market
- Forecasts & conclusions

# AVICENNE PROFILE

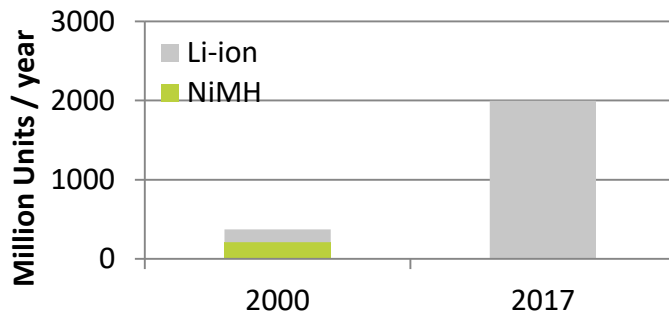
Information for Growth - Powering your company's market strategy with in-depth research

- ✦ Creation: 1992, by Ali MADANI
- ✦ Headquarter: Paris
- ✦ Liaison Office: Japan, USA, China
- ✦ AVICENNE Energy Director: Christophe Pillot
- ✦ 4 consultants
  - ✦ A Madani
  - ✦ C Pillot
  - ✦ JP Salvat
  - ✦ A Yassari
- ✦ 2 Senior advisors
  - ✦ X Zhang
  - ✦ M. Sanders
- ✦ Database: >20 000 contacts in the battery value chain

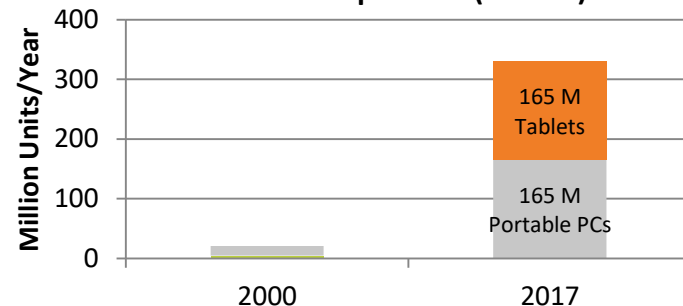


# THE BATTERY MARKET IS REALLY DYNAMIC

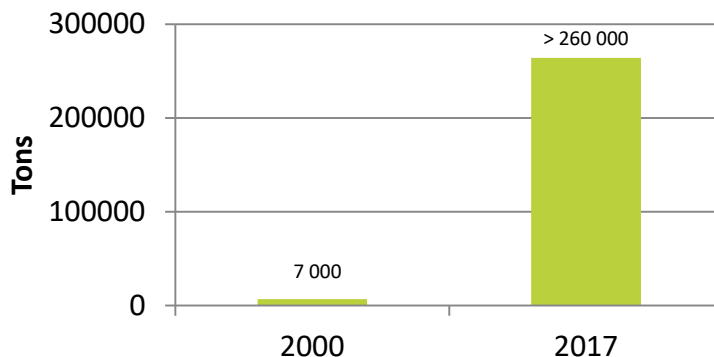
Cellular Phones sold per Year (Million)



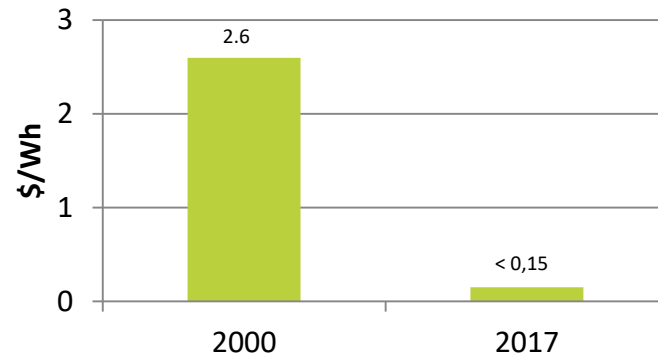
Portable PC sold per Year (Million)



Tons of cathode active materials

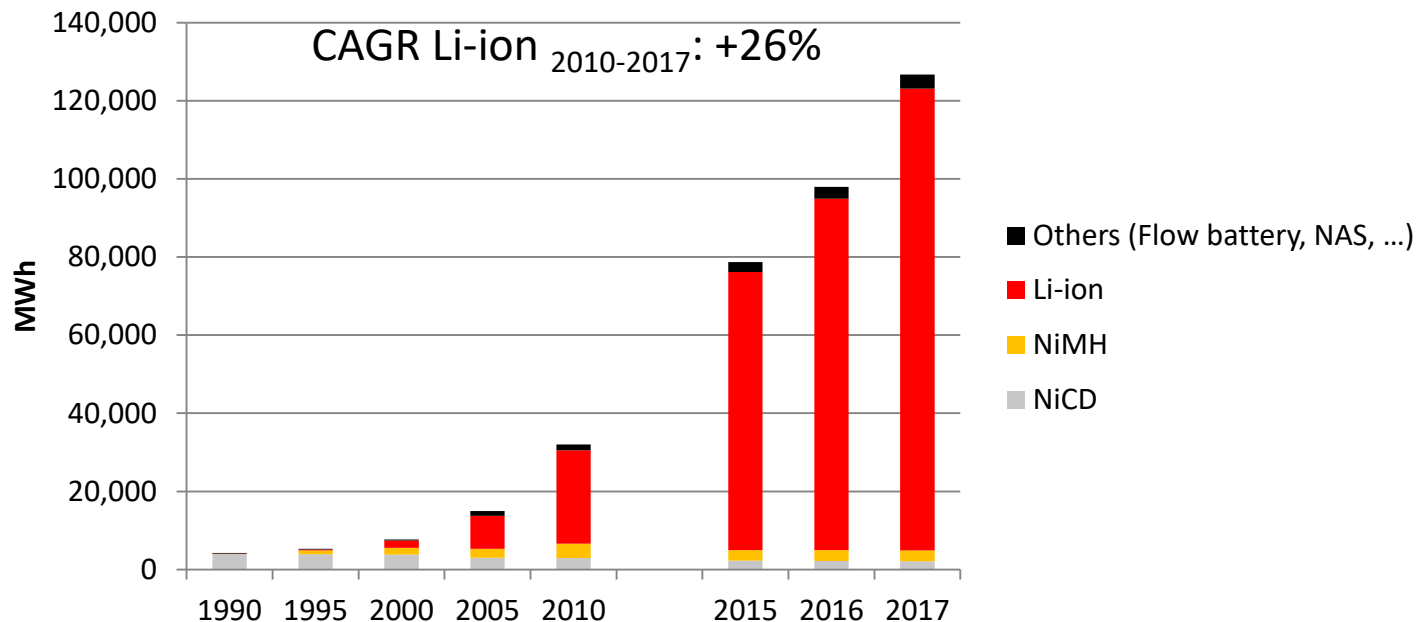


Li-ion 18650 cell price (\$/Wh)



# THE WORLDWIDE BATTERY MARKET 1990-2017

Lithium Ion Battery: Highest growth & major part of industry  
investments



Source: AVICENNE ENERGY, 2018

Lithium ion, Lead Acid and  
other storage options  
2017 - 2025



March 7<sup>th</sup>, 2018  
Cleveland, Ohio

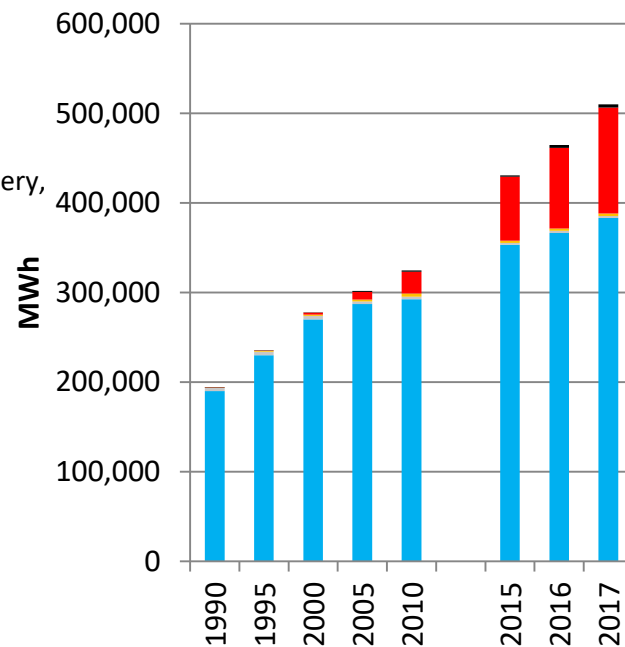
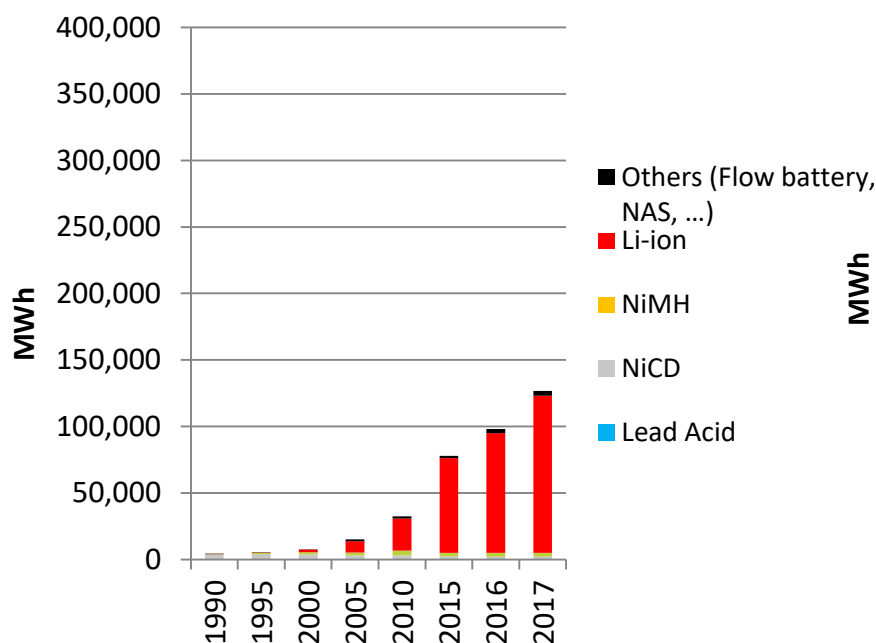
CONTACT

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# THE WORLDWIDE BATTERY MARKET 1990-2017

Lithium Ion Battery: Highest growth & major part of the investments  
Lead acid batteries: By far the most important market (90% market share)



Source: AVICENNE ENERGY, 2018

Lithium ion, Lead Acid and other storage options  
2017 - 2025



March 7<sup>th</sup>, 2018  
Cleveland, Ohio

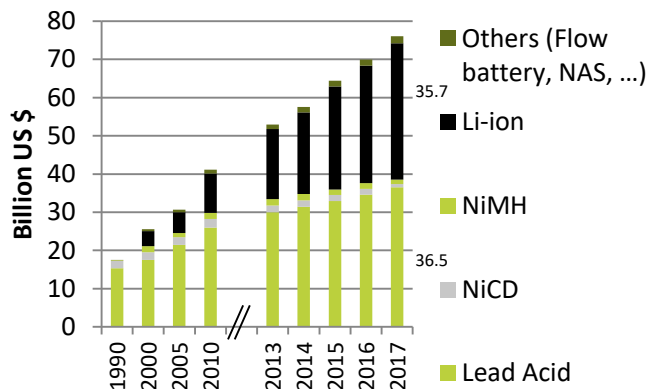
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# THE WORLDWIDE BATTERY MARKET 1990-2017

>75 BILLION US\$ in 2017 – Pack level<sup>1</sup>

9% AVERAGE GROWTH PER YEAR (2010-2017)



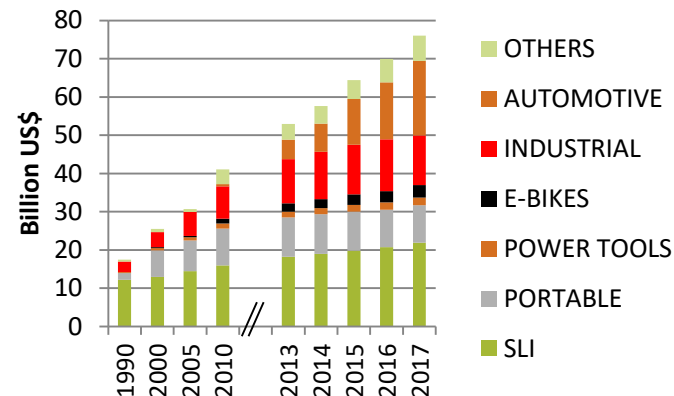
SLI: Start light and ignition batteries for cars, truck, moto, boat etc...

PORTABLE: consumer electronics (cellular, portable PCs, tablests, Camera, ...), data collection & handy terminals,

POWER Tools: power tools but also gardening tools

1- Pack: cell, cell assembly, BMS, connectors – Power electronics (DC DC converters, invertors...) not included

Source: AVICENNE ENERGY, 2018



INDUSTRIAL

- MOTIVE: Forklift (95%), others
- STATIONARY: Telecom, UPS, Energy Storage System, Medical, Others (Emergency Lighting, Security, Railroad Signaling,, Diesel Generator Starting, Control & Switchgear,

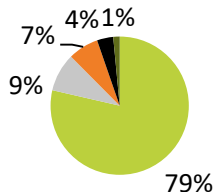
AUTOMOTIVE: HEV, P-HEV, EV

OTHERS: Medical: wheelchairs, medical carts, medical devices (surgical power tools, mobile instrumentation (x-ray, ultrasound, EKG/ECG, large oxygen concentrators, drones, Light Electric Vehicles, Hoverboard, ...

# THE LEAD ACID BATTERY MARKET BY APPLICATION AND TECHNOLOGY IN 2016

**Lead acid battery market in 2016:**

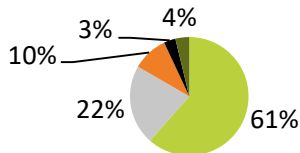
**367 GWH**



■ SLI 
 ■ Stationary 
 ■ Motive 
 ■ E-bikes 
 ■ Others

**Lead acid battery market in 2016:**

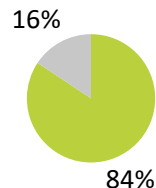
**US \$ 33 Billions**



■ SLI 
 ■ Stationary 
 ■ Motive 
 ■ E-bikes 
 ■ Others

**Lead acid battery market in 2016:**

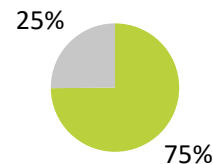
**367 GWH**



■ Flooded 
 ■ VRLA

**Lead acid battery market in 2016:**

**US \$ 33 Billions**

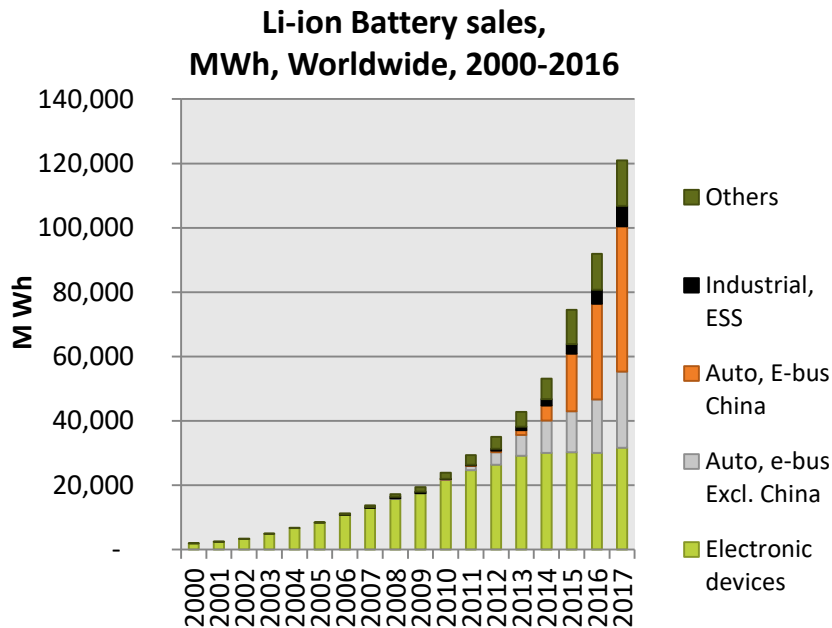


■ Flooded 
 ■ VRLA

# LI-ION IN 2017 - MAIN APPLICATIONS

>120 000 MWh - 27 B\$ (1)

CAGR 2007/2017  
 +25 % per year in Volume

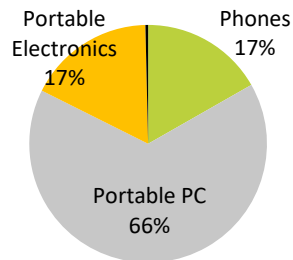


(1) Cell level

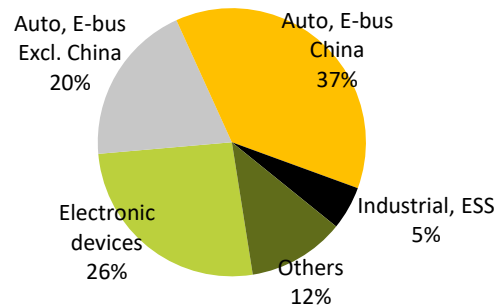
Others: medical devices, power tools, gardening tools, e-bikes...

Source: AVICENNE Energy 2018

2000: < 2GWh



2017: >120 GWh



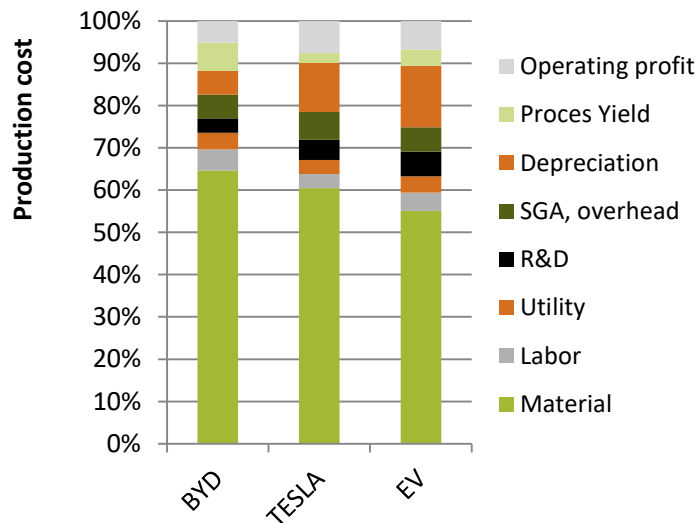


# LIB: THE BIGGEST PART OF THE COST IS RAW MATERIALS

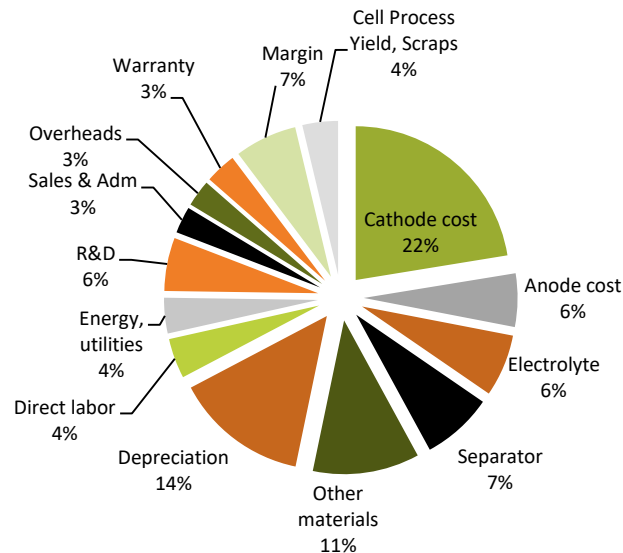
RAW MATERIALS ACCOUNT FOR 50 TO 70% OF LIB CELLS BUSINESS

RAW MATERIAL COST IMPACT DRASTICALLY ON THE BATTERY MAKERS PROFIT

**LIB Cost structure for TESLA & 40 Ah EV pouch cell NMC**

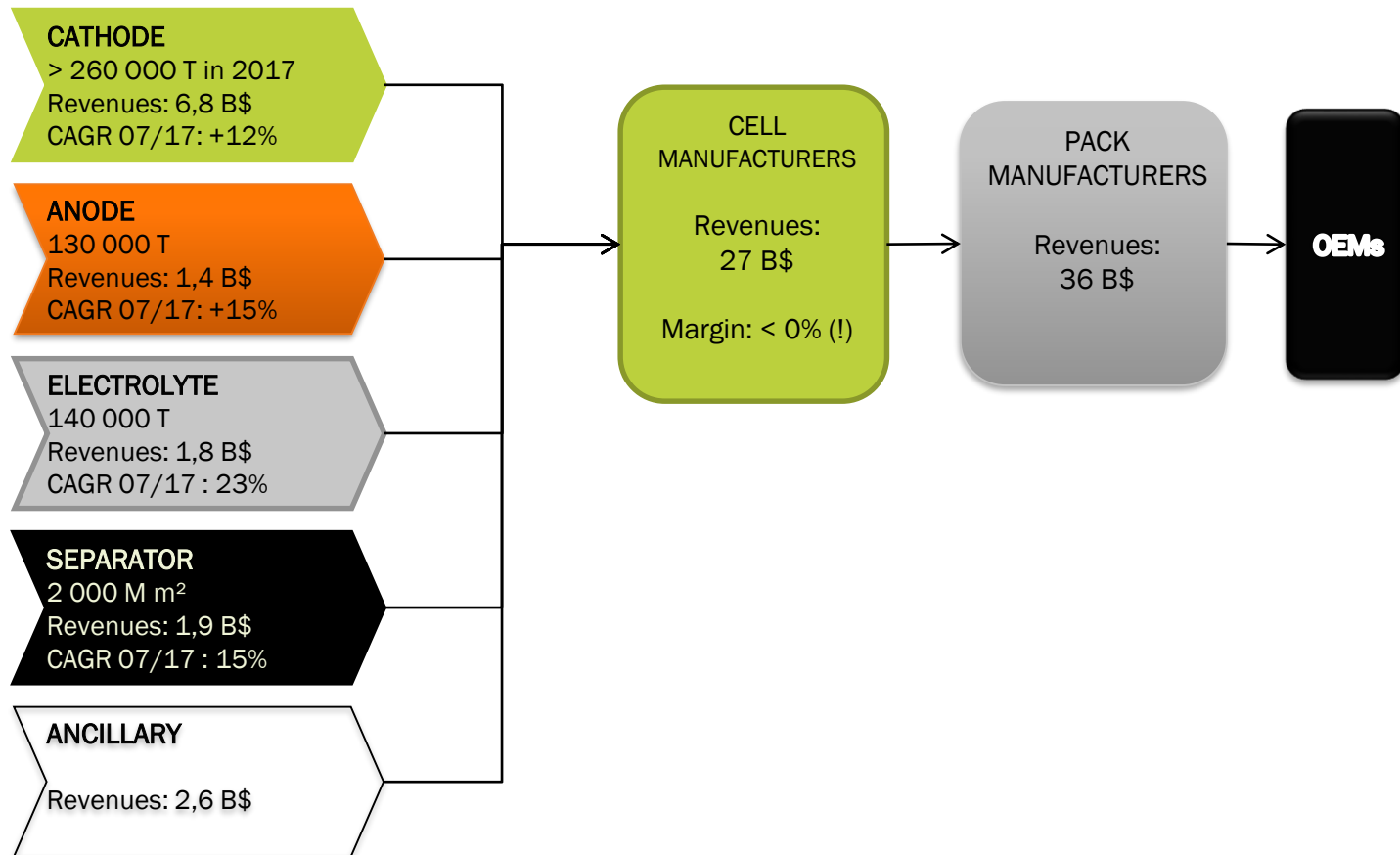


**Average cost structure of Li-ion cell**



Note: Average mix of cylindrical, prismatic & laminate cells  
 Sources: AVICENNE ENERGY 2017

# LI-ION VALUE CHAIN – MARKET DEMAND



# THE MAIN TRENDS

## Economical trends

Price decreases,  
Investment,

## Technical trends

new technologies, higher  
capacities, improving  
performances for raw  
materials,

## Regulation trends

Products banned,  
cyclability,

## Applications trends

xEV, ESS, Stationary, Mobile -  
Portable PC - Digital Cameras - PDA -  
Power Tools - Toys - Cordless Phones  
- Home Appliances - Camcorders -  
Security systems - RC Cars -  
Drones...

## Geographic Area

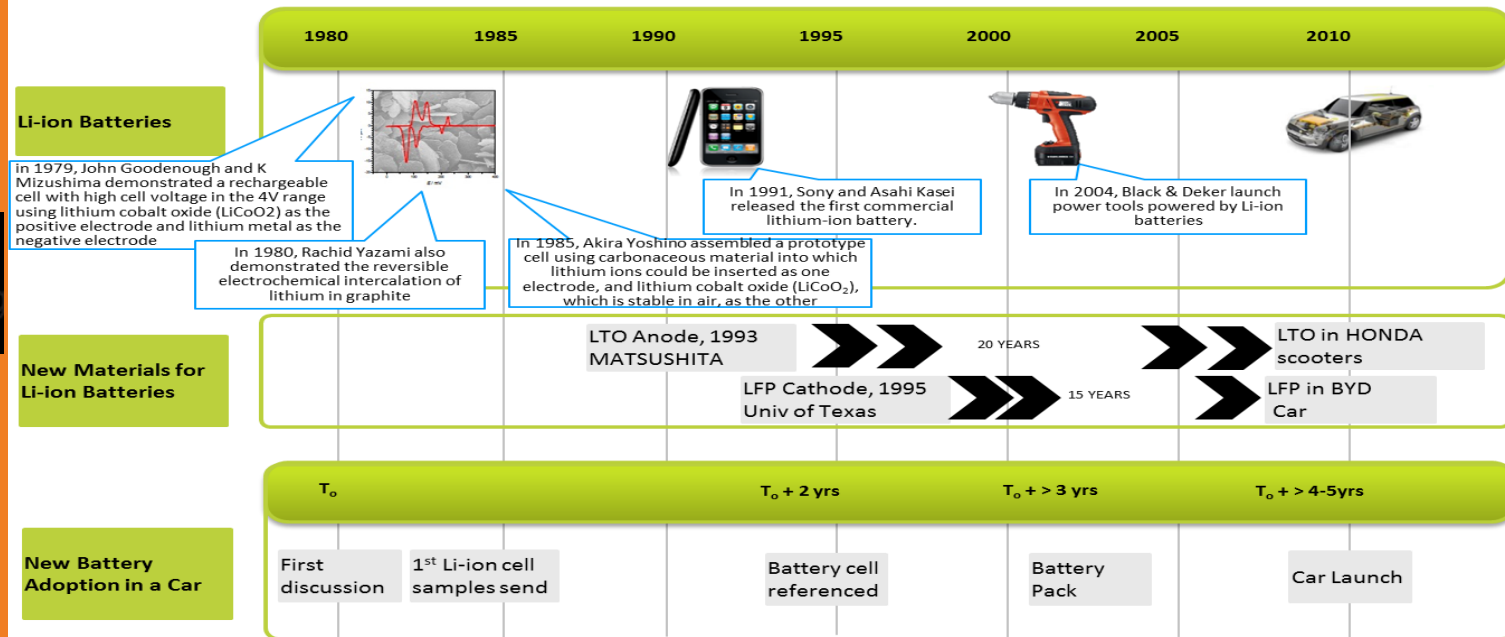
US - Western Europe - Japan -  
China - Latin America -  
Eastern Europe - Asia Pacific -  
Middle East - Row



## & SAFETY

# BATTERY TECHNOLOGY ROADMAP

Batteries take a long time to develop; to reach the automotive market, another 4 to 5 years are needed

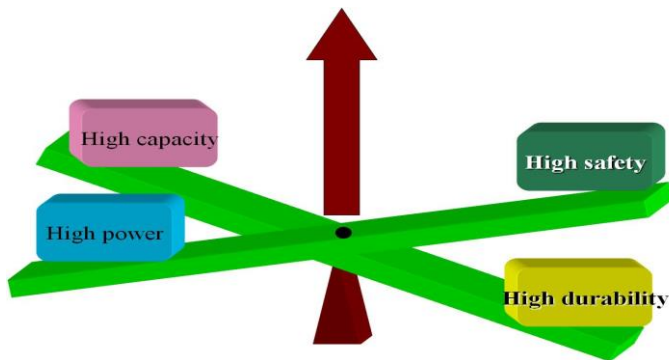


# LIB CATHODE MATERIAL

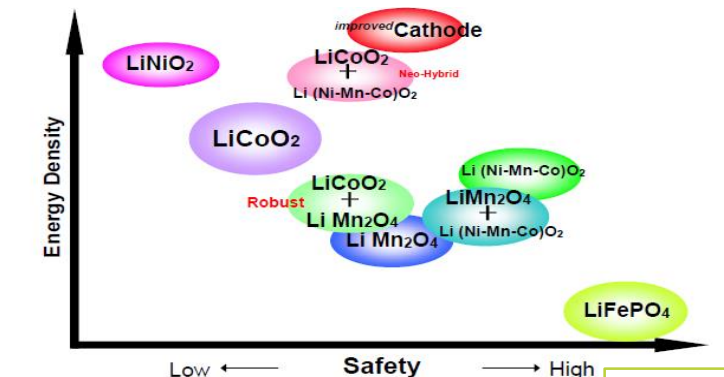
## ⌚ Cathode raw materials market

- ⌚ LiCoO<sub>2</sub> (LCO)
- ⌚ LiMn<sub>2</sub>O<sub>4</sub> (LMO)
- ⌚ LiMPO<sub>4</sub><sup>(1)</sup> (LFP)
- ⌚ Li[NixMnyCoz]O<sub>2</sub> - NMC
- ⌚ Li[NixCoyAlz]O<sub>2</sub> - NCA

(1) M= Fe or Mn

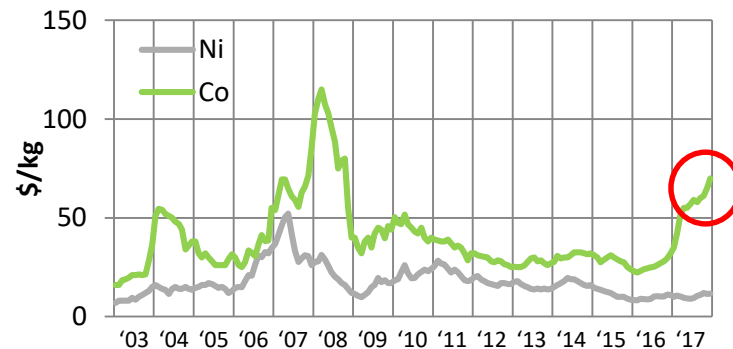


Source: Mitsubishi, Batteries 2012 – Nice



Source: SANYO, March 2011

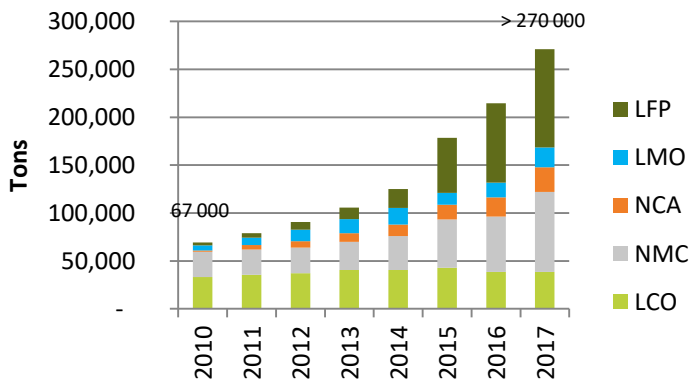
## Ni & Co price 2003-2017



Source: LME

# CATHODE ACTIVE MATERIALS NEEDS

Cathode active materials for LIB in Tons, 2010-2017 (Demand)



## LEADERS:



## NEW ENTRANTS ON THE FIELD:

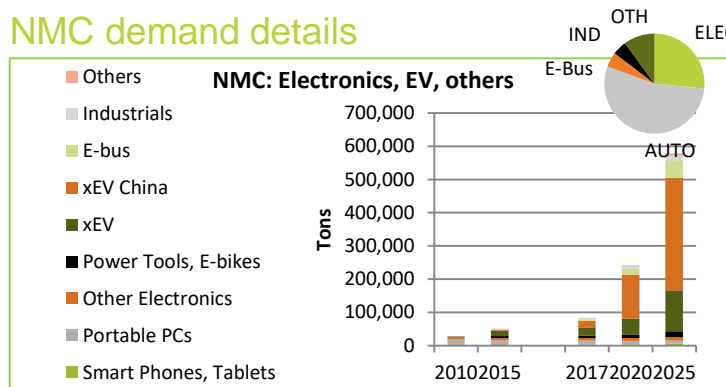


## Rationales

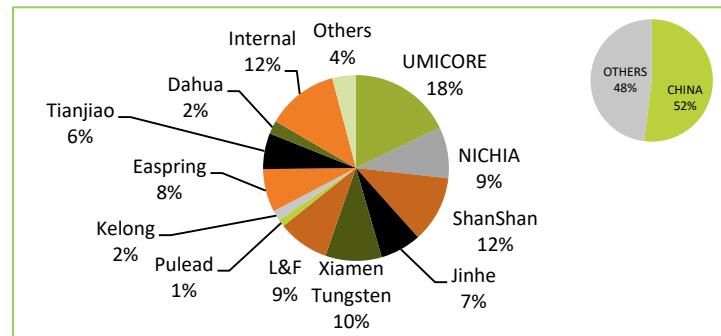
- In 2017, LCO is used in pouch cells for electronic devices: smartphones, tablets, ultra thin portable PCs
- NMC is used in other electronic devices & xEV
- NCA is used by 18650 Panasonic cells in Tesla cars and as a blend with LMO in other xEV
- LMO is mostly used as a blend with NMC in xEV
- LFP is used in xEV, e-buses in China and for industrial applications

# NMC DEMAND: CAGR 2016-2025: +21%

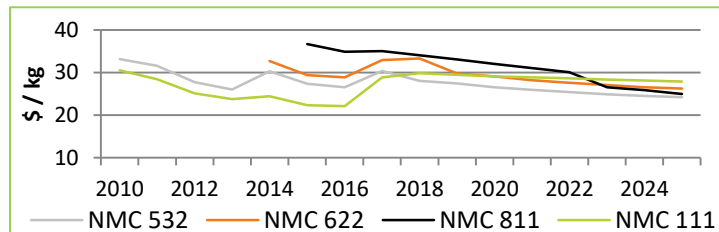
## NMC demand details



## NMC Offer in 2016/2017

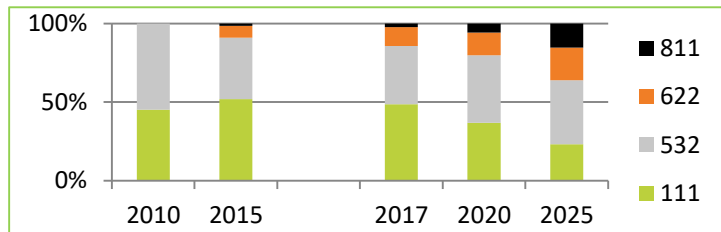


## NMC Price forecasts



Assumption: 2016-2025 : Co price stable @ 60\$/kg – Lithium carbonate stable @ 13\$/kg – Lithium hydroxide stable @ 16 \$/kg – Ni stable @ 12\$/kg

## NMC evolution

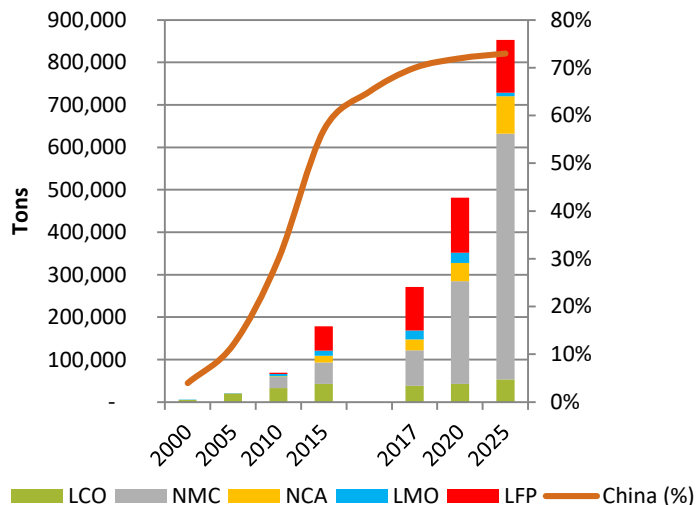


## NMC summary of outlook

**Demand:** Except xEV in China, **NMC** is driven by xEV: **Nissan** will switch from NCA-LMO to NMC for example. Then, **Toyota, Mitsubishi, Honda** all choose NMC. From 2012 to 2016 the clear trend was to switch from LMO-NMC 75/25 to LMO-NMC 25/75. **LG, Panasonic and Samsung** agreed that NMC will be the 1<sup>st</sup> choice for xEV first in Japan, US and Europe, and then, in 2020 in China. **Price** will decrease thanks to process manufacturing improvement. **Suppliers:** Umicore, L&F, and main Chinese (ShanShan) will keep the lead. LG and Samsung will outsource more (Internal part will decrease). As new entrant, BASF try to be on this market since 2011. There market share may increase.

# CATHODE ACTIVE MATERIAL FORECASTS 2000-2025

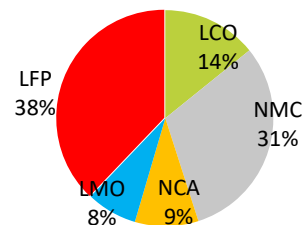
## Cathode active materials 2000-2025 - Tons



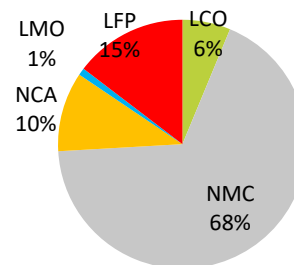
### ASSUMPTIONS:

- Portable devices:  
2017-2025: +5-6% per year in volume
- HEV: 3 M HEV/year in 2020, 4,2 M HEV in 2025
- P-HEV: 0,65 M P-HEV/year in 2020, 1,4 M in 2025
- EV: 1,9 M EV/year in 2020 (1,3 M in China) / 4 M/year in 2025 (2,8 M in China) 100% LIB
- Industrial, stationary & other applications 2016-2025: +16% per year

## Cathode active materials in 2016 > 270 000 Tons



## Cathode active materials in 2025 850 000 Tons



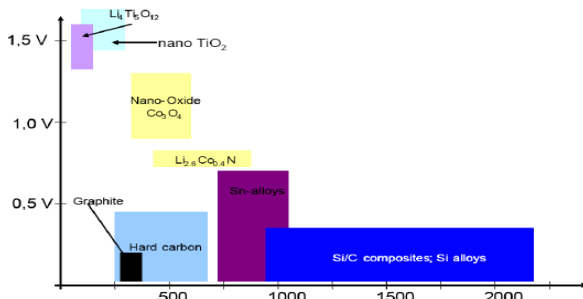
Assumption: Tesla keep NCA chemistry and have a relative success  
 (+350 000 EV sold per year in 2025 – TESLA forecast 500 000)



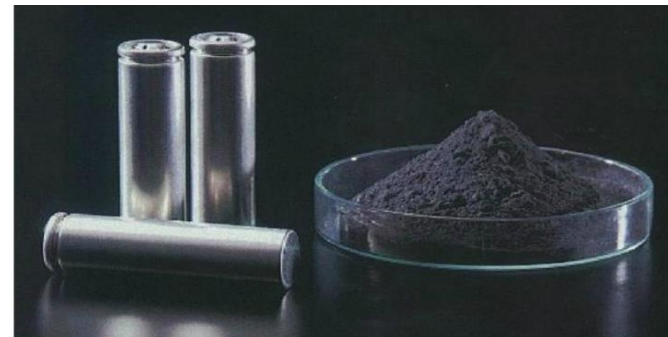
# ANODE ACTIVE MATERIALS

## 130 000 TONS IN 2017

### LIB Anode Materials

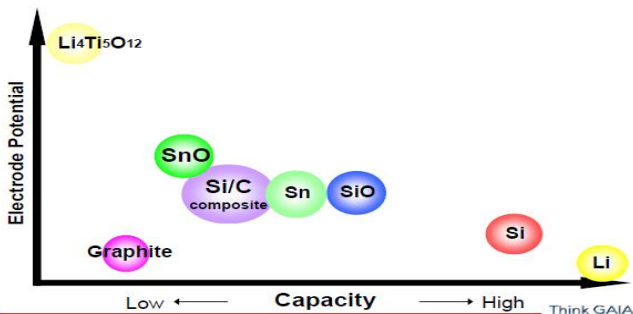


Source: A. Jossen, IRES 2007



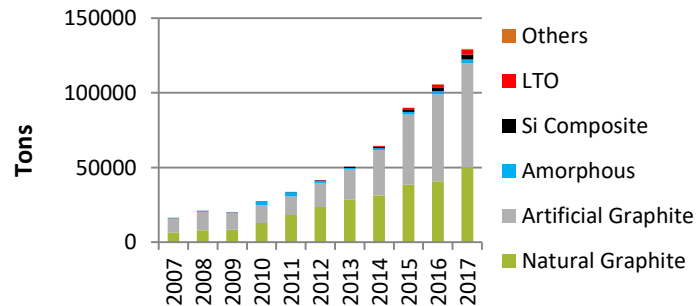
Source: Hitachi Chemical

### LIB Anode Materials



Source: Sanyo, March 2013

### LIB Anode market, (Tons)



Sources: AVICENNE ENERGY 2018 17



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Lithium ion, Lead Acid and  
other storage options  
2017 - 2025



March 7<sup>th</sup>, 2018  
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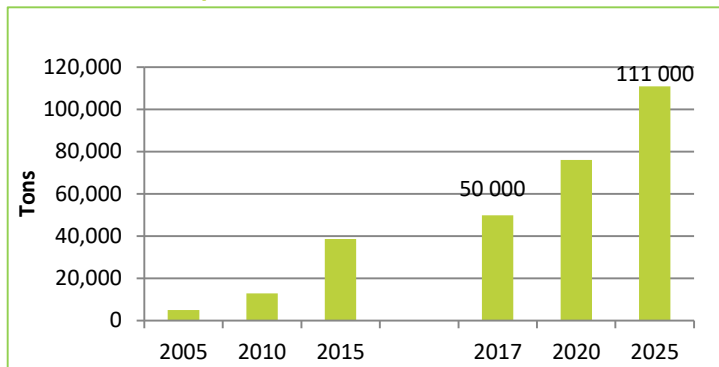
#### CONTACT

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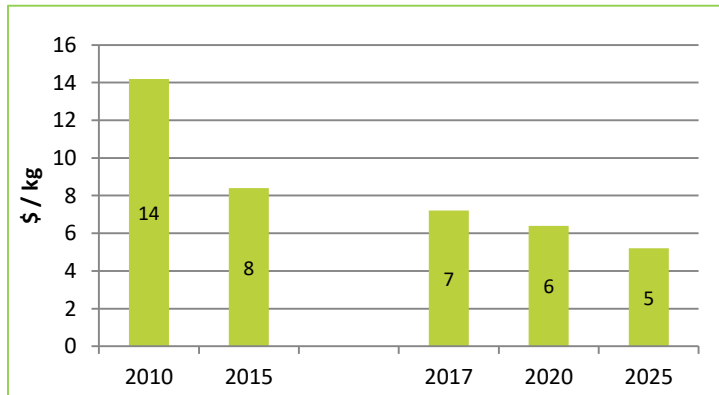
m.sanders@avicenne.com

# NATURAL GRAPHITE: CAGR 2017-2025: +6%

## Natural Graphite demand details

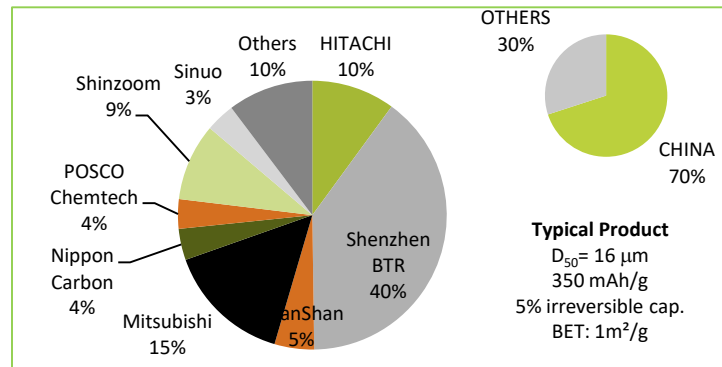


## NG Price forecasts



Sources: AVICENNE ENERGY 2017

## NG Offer in 2016



## NG summary of outlook

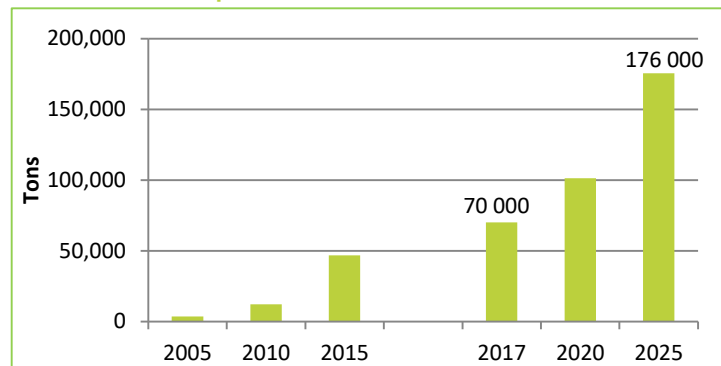
**Demand:** smaller growth because new app. Need artificial Gr and Chinese LIB choose mostly artificial Gr. This demand may change if the price decrease is more important for NG compare to AG. **Price:** The price will decrease fast because the supply is huge. Already over supply in China ( Capacity: BTR 30 000 Tons, Zichen: 10 000 Tons, Shinzom: 10 000 Tons, Sinuo: 8 000 Tons, Qingdao: 8 000 Tons, Jianxi Zhentuo: 7000 Tons, Kimwan: 5 000 Tons...). Then, a lot of new projects in China and Canada: Focus Graphite > 40000 Tons/year (2020\*), Northern Graphite > 20 000 Tons/year (after 2018\*) Syrah Resources Ltd. > 80 000 Tons (2020\*)

**Suppliers:** BTR and new Chinese (Zichen thanks to ATL, - Shinzom thanks to BYD, CATL – Sinuo etc...). New entrant like Focus Graphite, Northern Graphite, or Syrah Resources Ltd. May change the market share in the future

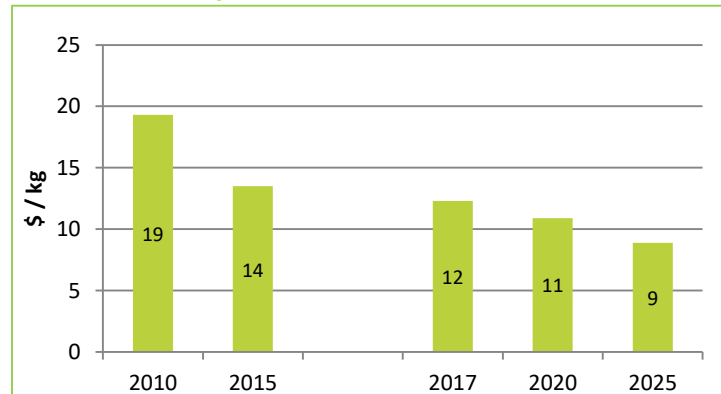
\* Subject to financing

# ARTIFICIAL GR.:CAGR 2017-2025: +8%

## Artificial Graphite demand details

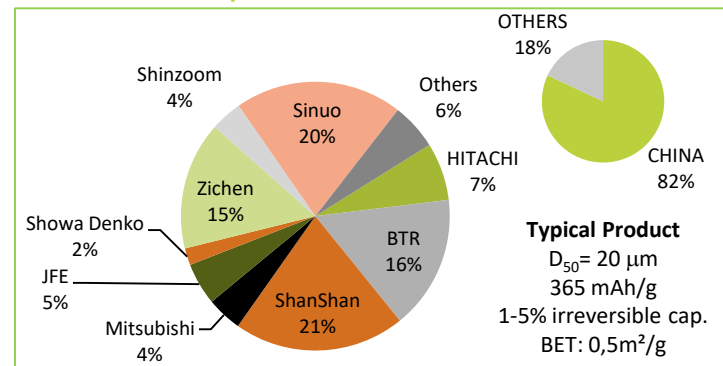


## Artificial Graphite Price forecasts



Sources: AVICENNE ENERGY 2017

## Artificial Graphite Offer in 2016



## Artificial Graphite summary of outlook

**Demand:** The demand will increase fast thanks to xEV market and Chinese market. Long life time requirement involve high level of purity and high consistency, difficult to achieve with Natural Graphite.

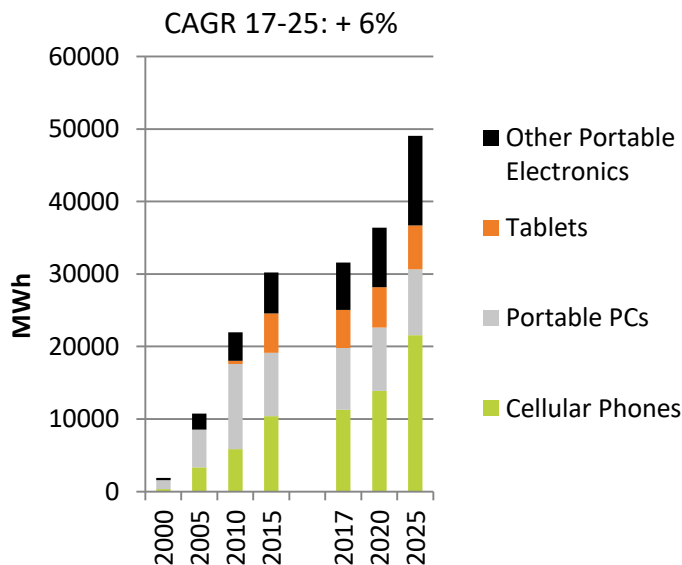
**Price** will decrease fast thanks to better process efficiency, new process

**Supply:** Thanks to the best quality, Hitachi will keep the lead but Chinese main suppliers market share will increase (ShanShan mostly).

**Production Capacity:** Hitachi: 15 000 Tons, ShanShan: 15 000 Tons project in Lingang Park (Shanghai) to add 20 000 Tons/year, Mitsubishi: 7 000 Tons, JFE: 7000 Tons, Showa Denko: 3000 Tons

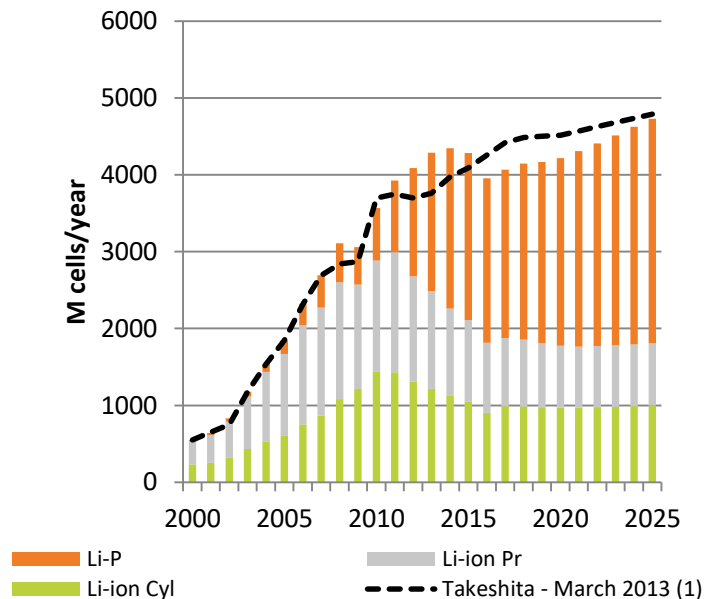
# 2025 LIB FORECASTS FOR PORTABLE ELECTRONIC DEVICES

2000-2025 LIB market, MWh, by application (3C)



Source: AVICENNE ENERGY Analyses

2000-2025 LIB market, M cells, by form factor (3C)

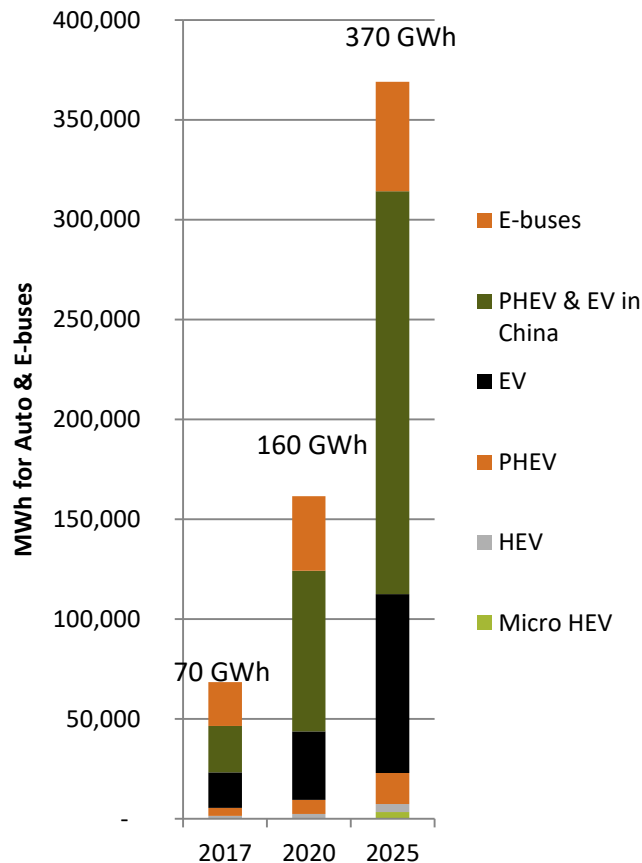


(1) Source: Takeshita, Battery Japan 2013 BJ-3 conference Slide p 4

# X-EV MARKET

- Why x-EV ?
- Definition & segmentation
- X-EV worldwide in 2017
  - By country
  - By car makers
  - By battery chemistry
- X-EV forecasts
  - AVICENNE ENERGY & other analyst forecasts
  - Battery chemistry forecasts
  - Battery cost forecasts
- X-EV battery forecasts

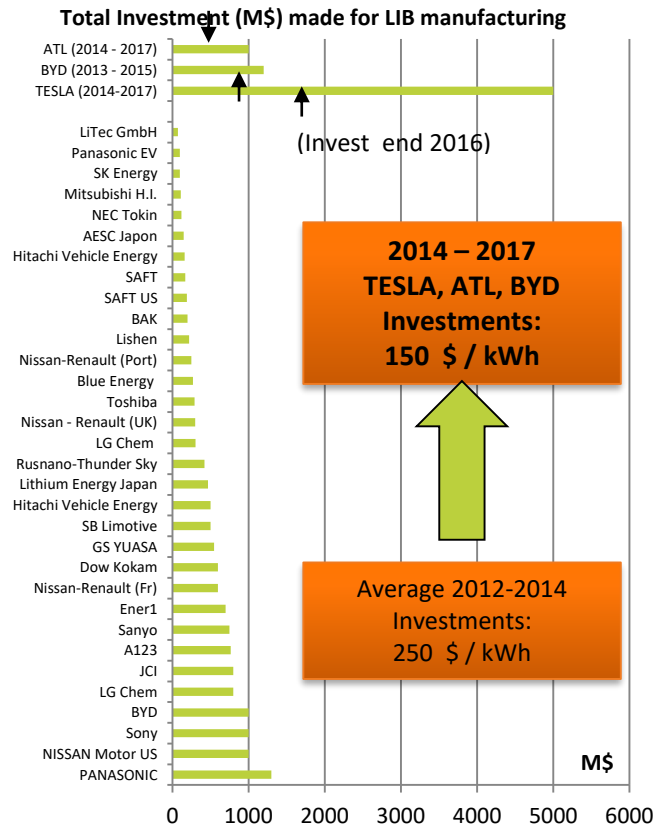
**CAGR 2017-2025: + 23%**



# LIB MANUFACTURING INVESTMENTS 2009-2017

10-12 B\$ WORLDWIDE (>50 GWh invest from 2011 to 2014)

7 B\$ invested from 2014 to 2017 by TESLA (5), BYD (1,2), ATL (1)



TESLA Plant, Nevada, Feb 2015



TESLA GIGA FACTORY, Dec 2016

Lithium ion, Lead Acid and  
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2017 - 2025



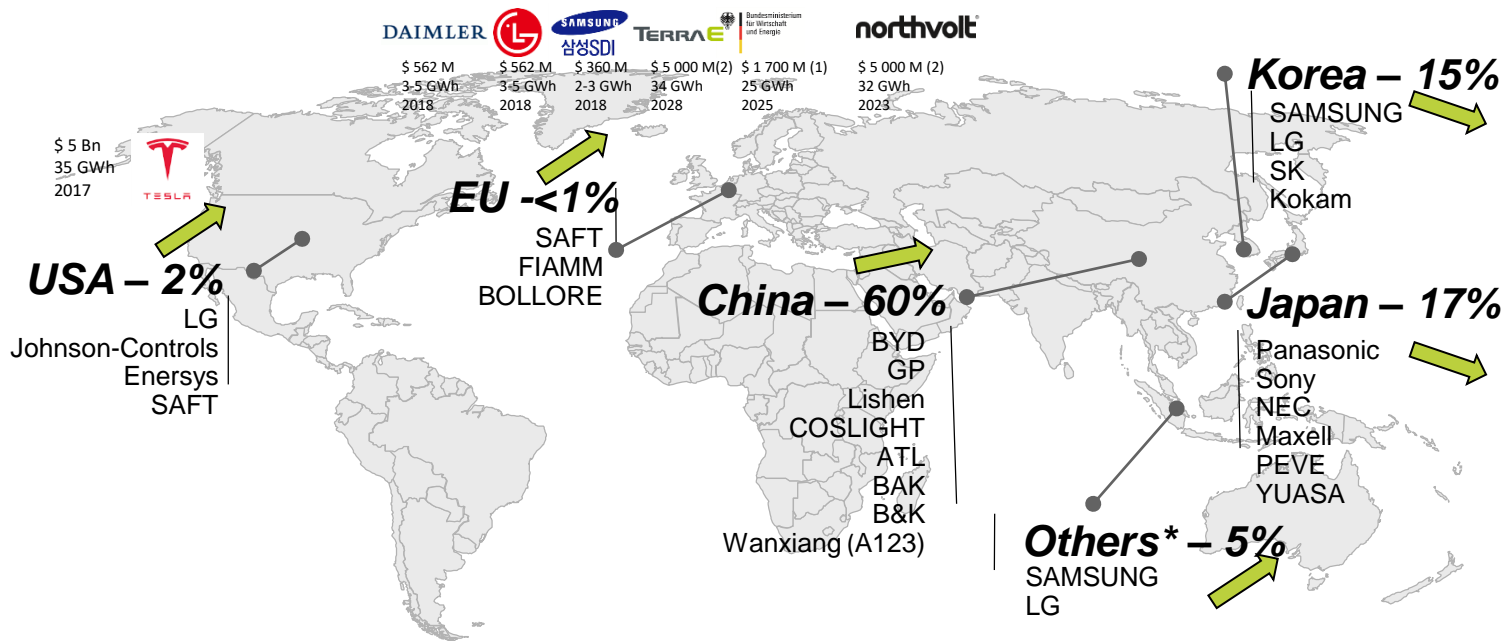
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# LITHIUM ION CELL PRODUCTION

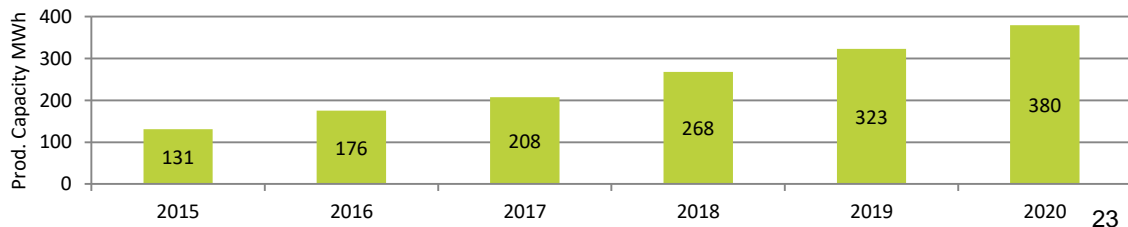
Korean companies start to move in Malaysia

New production capacity in Europe and US



Source: AVICENNE 2017

\* OTHERS: Malaysia mostly  
 (1) Government subsidies only  
 (2) AVICENNE Estimation



Lithium ion, Lead Acid and  
other storage options  
2017 - 2025



March 7<sup>th</sup>, 2018  
Cleveland, Ohio

CONTACT

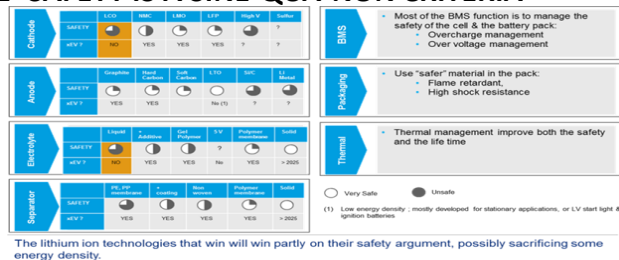
Michael SANDERS  
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# THE LITHIUM ION BATTERY MARKET FORECASTS

## 3 major limiters on batteries, for the development of electric vehicle

### 1- SAFETY IS A SINE-QUA-NON CRITERIA



The lithium ion technologies that win will win partly on their safety argument, possibly sacrificing some energy density.

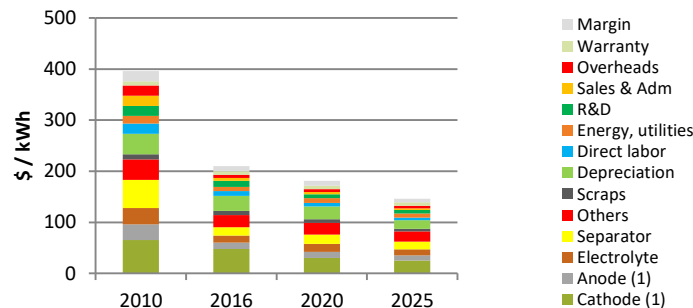
### 2- TIME TO MARKET

- The research and development in this industry is very long and time consuming.
- Time to market to commercialize a new material is long. Remember that the first Li-ion battery was launched by Sony in 1991 with LCO cathode, graphite, LiPF<sub>6</sub> electrolyte & polyolefin membrane. It was 20 years ago.
- LTO was invented by Matsushita in 1993 (22 years ago)
- Lithium iron phosphate was invented in 1995 (20 years ago).
- So, it takes between 10 & 20 years to commercialize a new material in the battery industry.

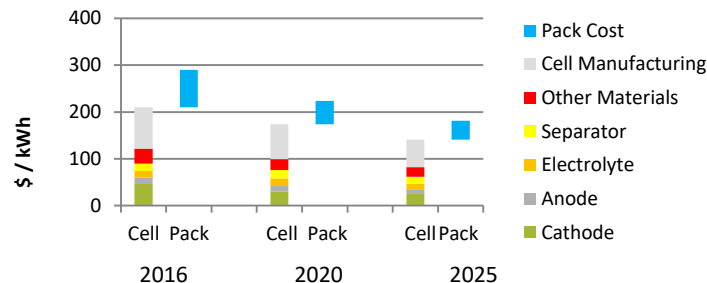
(1) Active material only

### 3- BATTERY COST

Average Cell price

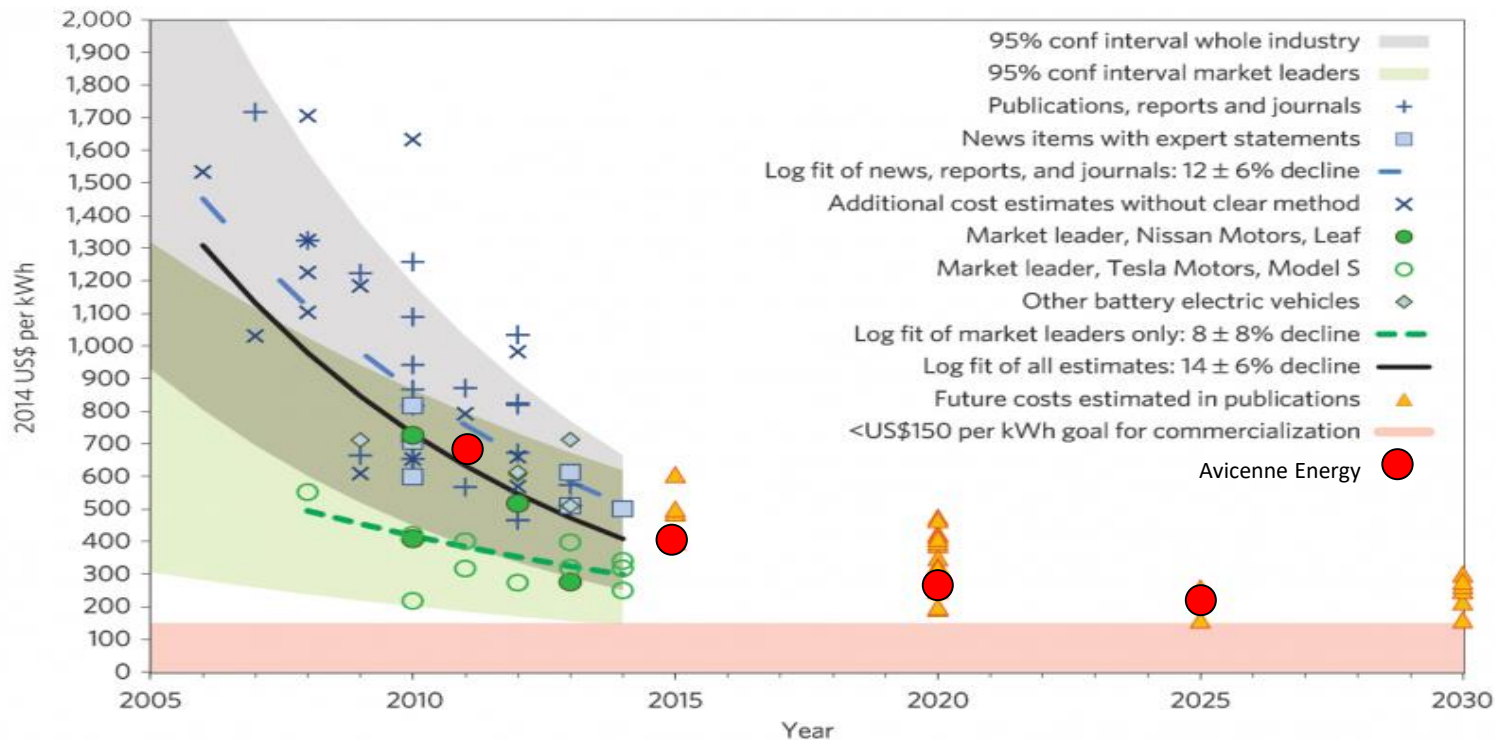


Average Pack price



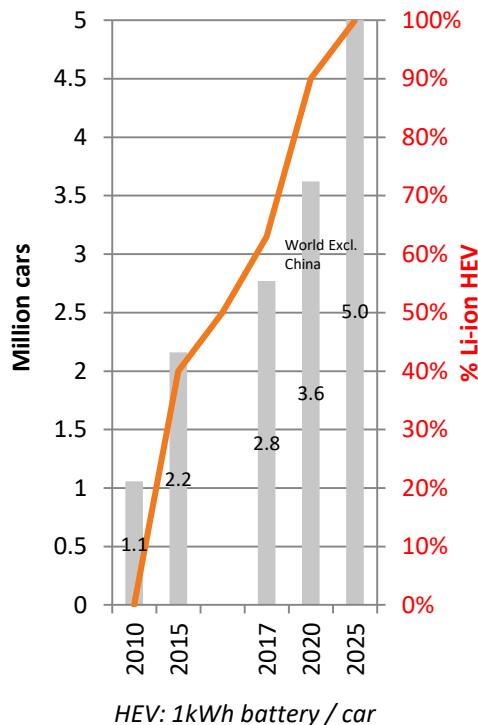


# LIB PRICE FORECASTS

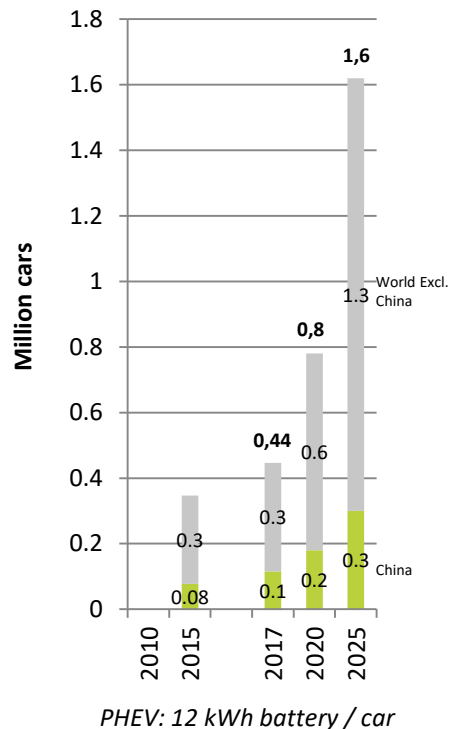


# HEV, P-HEV, EV 2025 FORECASTS

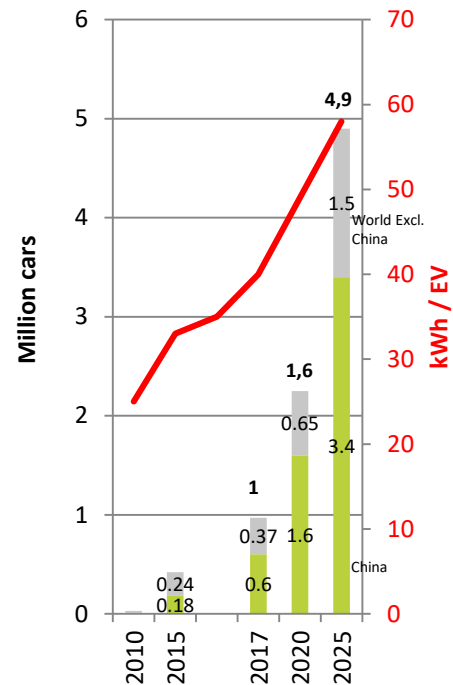
## HEV manufactured



## PHEV manufactured



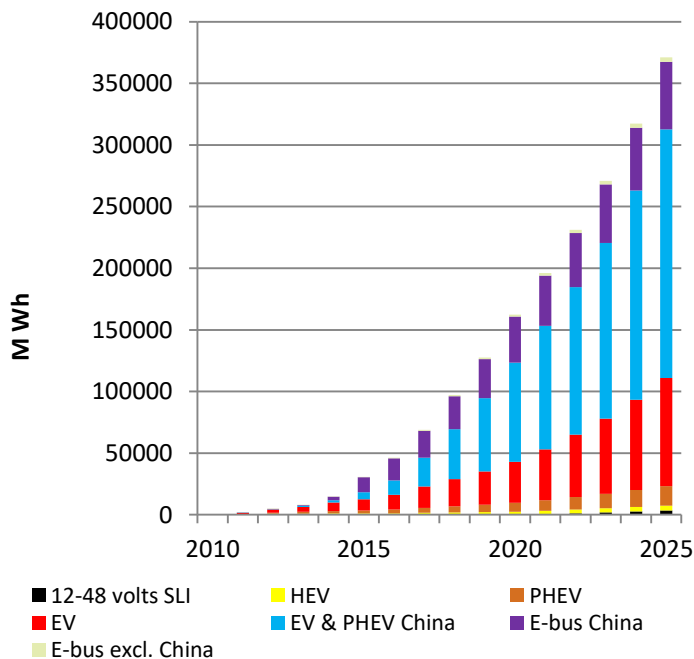
## EV manufactured



# TOTAL BATTERY DEMAND 2025 FORECASTS

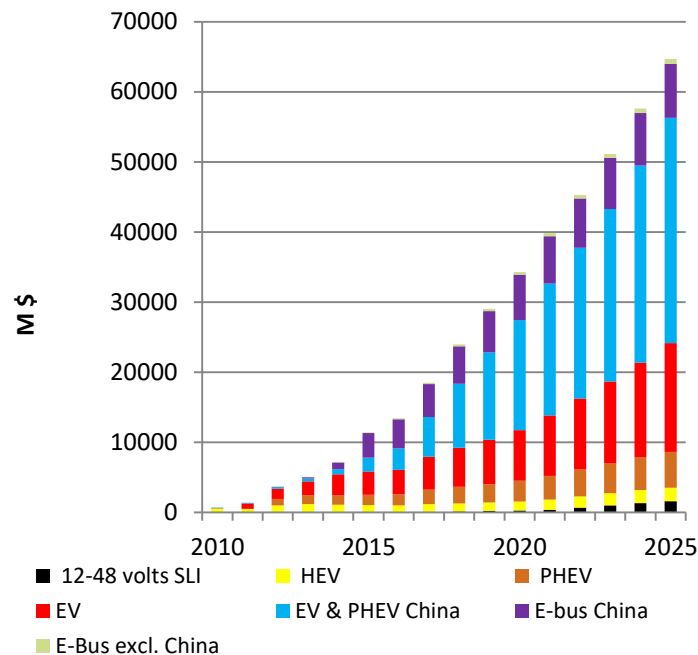
Li-ion for EV, HEV & P-HEV Battery  
needs (MWh)

CAGR 2017-2025: +23%



Li-ion for EV, HEV & P-HEV Battery  
needs (M\$)

CAGR 2017-2025: +17%

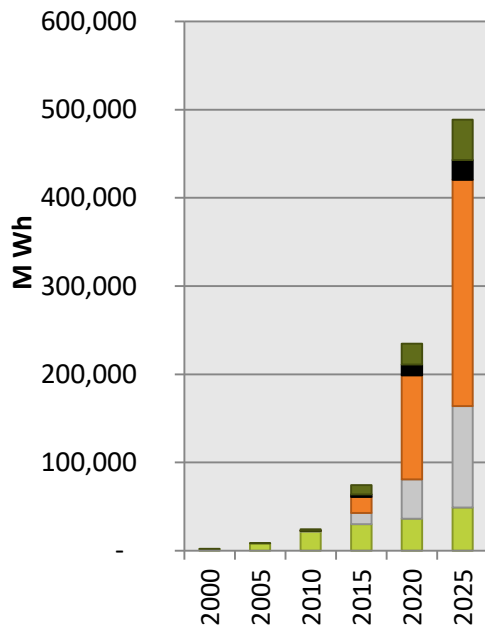


# LI-ION BATTERY MARKET FORECASTS

From 120 GWh in 2017 to 490 GWh

CAGR 2017/2025  
+19 % per year in Volume

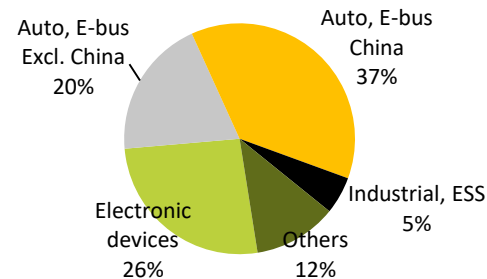
**Li-ion Battery sales,  
MWh, Worldwide, 2000-2025**



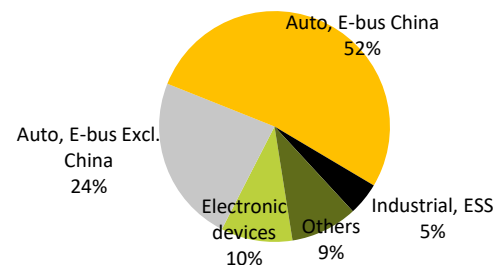
CAGR 15/25  
(Realistic)

Others	16%
Industrial, ESS	22%
Auto, E-bus China	30%
Auto, e-bus Excl. China	25%
Electronic devices	5%

**2017: >120 GWh**



**2025: 490 GWh**



*Others: medical devices, power tools, gardening tools, e-bikes...*

Source: AVICENNE Energy 2018

Lithium ion, Lead Acid and other storage options  
2017 - 2025



March 7<sup>th</sup>, 2018  
Cleveland, Ohio

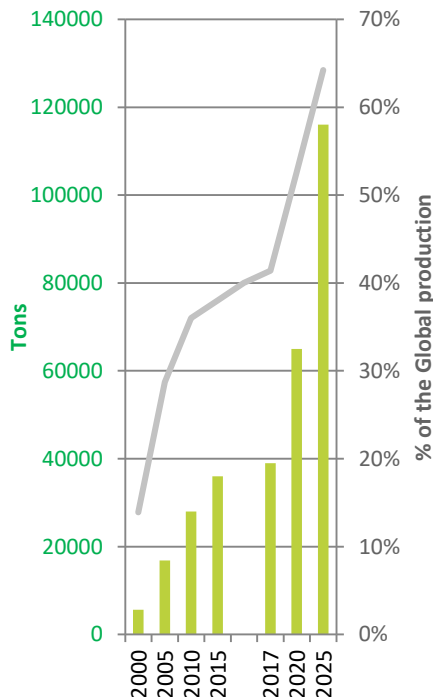
CONTACT

Michael SANDERS  
302-540-9457

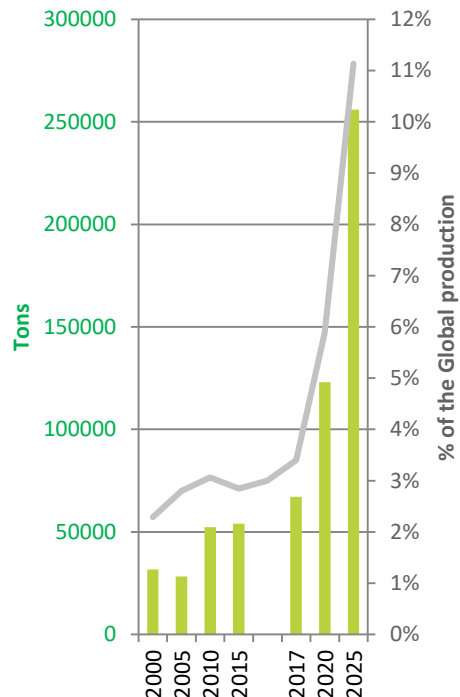
[m.sanders@avicenne.com](mailto:m.sanders@avicenne.com)

# METAL NEEDS FOR RECHARGEABLE BATTERY WILL INCREASE RAPIDLY

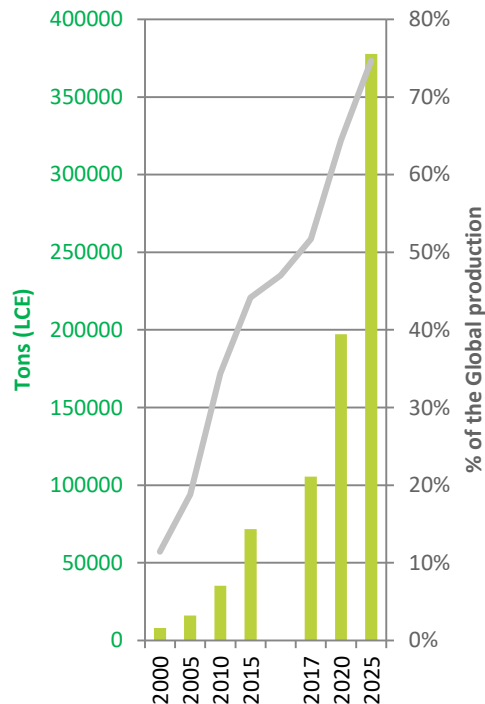
## Cobalt



## Nickel



## Lithium



Sources: AVICENNE ENERGY 2018

Lithium ion, Lead Acid and  
 other storage options  
 2017 - 2025



March 7<sup>th</sup>, 2018  
 Cleveland, Ohio

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# TIME TO MARKET FOR NEW MATERIALS



	2000	2005	2010	2015	2020	2025	2030
CATHODE	LCO		NMC/NCA LMO LFP	LiNiMnO <sub>2</sub> High voltage	5v spinel LiNiPO <sub>4</sub> , 5v LiCoPO <sub>4</sub> , 5v LiMnPO <sub>4</sub> , 4v	Sulfur	Air
ANODE	Graphite Hard Carbon		Soft Carbon Li <sub>4</sub> Ti <sub>5</sub> O <sub>12</sub>		C/Alloy Composite Non Si Alloys	Li Metal Si Alloys	
ELECTROLYTE	LiPF <sub>6</sub> + Org. solvents		LiPF <sub>6</sub> free electrolyte	Gel-polymer electrolyte	5v electrolyte		
SEPARATORS	Polyolefin		Polyolefin+ ceramic coating	Cellulose Non-woven		Polymer membrane	Solid Electrolyte

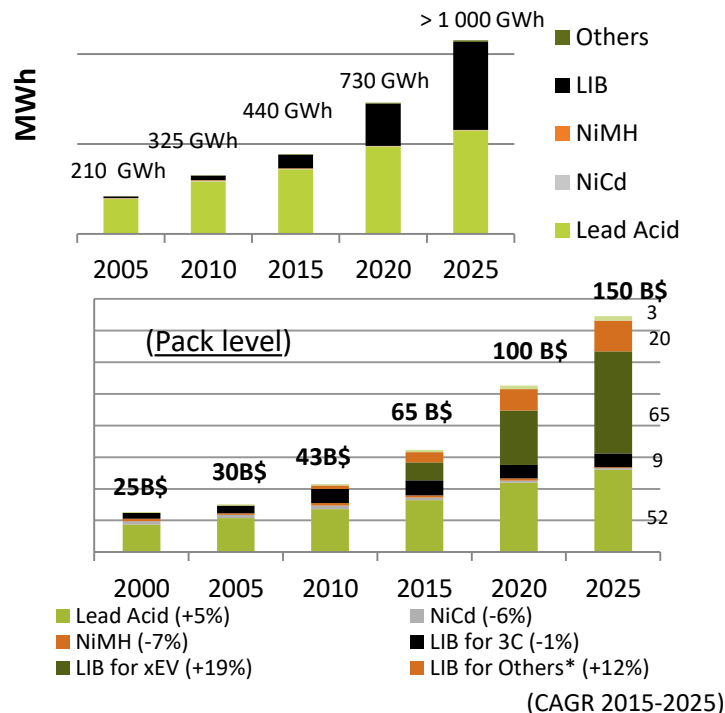
Source: AVICENNE ENERGY 2016

# TAKEAWAYS

Battery Market 2015-2025 - CAGR = +9% / Li-ion>+13%

- Li-ion battery is driven today by Automotive & Industrial applications
- In 2012, most of the car makers (except Toyota) switch to Li-ion for HEV
- P-HEV, EV and E-buses will be powered by Li-ion: 18 B\$ market in 2017 - 34 B\$ in 2020 & 65 B\$ in 2025 with high numbers in China (2017: US\$6 Billion for xEV and US\$ 5 Billion for xE-Buses)
- EV expectations attract large Chemical companies
- New materials are needed to meet Automotive standards
- HEV will account for 3% of the auto sales in 2020
- P-HEV & EV for 2% to 3% by 2020
- Micro-hybrid will achieve >50% in 2020/25
- Lead acid battery will be the first market in 2025 in volume, but Li-ion market will be higher than Lead acid in value from 2018.
- A very small EV market in the automotive world will represent a huge market for batteries
- New LIB applications: UPS, Telecom, Forklift, Medical, Residential ESS, Grid ESS, hoverboard, drones: CAGR > 10% in the next 15 years
- Lithium battery for other application (ESS, stationary, industrial...) will reach 10 Billion \$ market at the pack level in the next 5 years
- ESS market could be much more important if the price of LIB at the system level is under 150 \$/kWh

## RECHARGEABLE BATTERY MARKET WORLDWIDE 2000-2025



Others: Automatic handling equipment, robots, forklifts, back-up, UPS, Telecom, medical devices, Residential ESS, Grid ESS, drones, Hoverboard.....



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Thank You



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